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Observations from Three Years of Implementing an Inverted (Flipped) Classroom Approach in Structural Design Courses

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Abstract

An inverted (flipped) classroom approach has been used by the authors for the previous three years in a required upper-level undergraduate course in Structural Design (Structural Steel/Reinforced Concrete) at Villanova University. Previously, the course had been taught in a classical manner, with about two-thirds of a typical class meeting period devoted to a lecture and the remainder devoted to solving quick problems using a PowerPoint format. In the inverted format, students are required to watch the lectures emphasizing theory outside of the classroom and nearly all of the in-class time is spent solving problems in a real-time manner using a TabletPC.

This paper reviews the motivation behind the decision to switch to the inverted format and explains the intended beneficial impacts on student learning. Details on the structure and relationship of individual course components in the inverted model (recorded lecture videos, concept quizzes, problem sets, laboratory exercises, and design projects) are presented. Impacts on faculty planning and preparation are discussed. A review of the changes made between each successive course offering based on lessons learned is also provided.

In addition to the authors' (faculty) perspective, the students' perspective is also addressed based on the results of extensive end-of-the-semester surveys asking students for feedback on the inverted model. Student responses to numerous multiple choice "rating" questions about course format and course components are provided. Student performance is also addressed through a broad comparison of examination grades in the different course offerings.

Introduction

The inverted classroom format is a topic that has received a great deal of attention recently, particularly in the area of engineering higher education. The inverted or "flipped" classroom typically involves moving most or the entire lecture component of the course outside the classroom, allowing more time in class for active learning and group activities that may have traditionally occurred outside the classroom. The lecture component can be delivered in multiple formats, with the most common approach being a video or screen capture of the instructor delivering the lecture. A strong indicator of the interest in the topic can be seen by conducting a search of the 2014 ASEE conference proceedings for the term "inverted classroom" which returns 51 articles. Bishop and Verleger conducted a survey of the research on flipped classrooms in 2013 and found 39 unique blog posts or online articles devoted to the topic.[1]

The reasons for the substantial interest in the inverted classroom format are well founded in the literature. Active learning has been demonstrated to be beneficial for learning for the vast majority of students in engineering classes.[2] However, there is a general perception that with the fixed time in the classroom and apparently ever increasing demands on that time, it is difficult to find the time to include significant active learning components. The inverted classroom can be used to increase the classroom time for active learning without reducing the content covered in the course.[3] Also, the inverted classroom allows for learning to occur in a format that more closely resembles how students will be required to learn as practicing engineers, helping to establish the foundation for lifelong learning.[4] Finally, the inverted classroom allows for the flexibility to present information in a variety of formats, better accommodating the diverse learning styles present within the class.[5]

However, the inverted classroom format is not without challenges. Initially, an inverted class requires an increased time commitment by the instructor.[3] In addition, there are potential pitfalls that must be navigated to ensure a positive, effective learning environment. These can include the length and structure of the videos, accessibility of the supplemental (outside of class) content, and motivating the students to take responsibility for their own learning.[6] Multiple solutions have been proposed for each of these pitfalls, but the specific methods used for each course must depend on the content of the course, the characteristics of the instructor teaching the course, and the abilities and experiences of the students taking the course.

This paper presents the experiences gained navigating these and other pitfalls while inverting a junior/senior level structural design course in the Department of Civil and Environmental Engineering at Villanova University. The course was first inverted in 2012, and since then substantial changes have been made to the way in which the inverted course was administered. The inversion is part of a larger focus on investigating the inverted course structure within the College of Engineering.[7] In addition to a providing a description of the various inverted course components used, this paper presents student performance data and student opinions on the overall course structure and specific components of the inverted classroom structure.

Evolution of Structural Design Courses at Villanova University

Prior to 2014, students pursuing Bachelor of Science in Civil Engineering (BSCE) degrees at Villanova University were required to take a three-credit course CEE 3412: Structural Design and a separate one-credit laboratory course CEE 3912: Structural Engineering Lab. These courses were typically taken during the second semester of the junior year and addressed the behavior, analysis, and design of both structural steel and reinforced concrete members. A required course CEE 3401: Structural Analysis was typically taken in the first semester of the junior year and was a prerequisite for both CEE 3412 and CEE 3912. The CEE 3401/3412/3912 seven-credit sequence in structural analysis and design thus defined the required track in structural engineering for all students within Villanova University's broad-based undergraduate curriculum. Similar required course sequences existed in the other disciplinary areas of transportation, geotechnical, water resources, and environmental engineering with a set of primarily junior-level courses that have companion lab courses. Students interested in structural engineering could pursue an additional elective course option in the senior year (CEE 4412: Advanced Structural Engineering) and later elect to enroll in the Structural Engineering Capstone design section.

The course sequence in structural engineering had been offered in this form since 2001. Over the past few years, a number of significant changes have been introduced with this sequence. In 2012, the primary structural design course (CEE 3412) was redeveloped using an inverted classroom format. The course was offered in this format for two years, with some minor changes introduced in the second year. In 2014, CEE 3412 and CEE 3912 were eliminated and replaced with two new courses that separate the content associated with steel and concrete. The two new courses are CEE 3402: Structural Steel Design and CEE 4404: Reinforced Concrete Design. Both courses utilize an inverted classroom format and include an integrated laboratory component. All BSCE students must take at least one of the two courses as a degree requirement, while students with an interest in structural engineering may choose the second course as an elective. This change eliminated the previously offered senior elective (CEE 4412), which primarily addressed modern structural analysis techniques covered in an introductory graduate level course that qualified students may still take. The change also effectively reduced the required track in structural engineering by one credit hour (from seven to six).

The evolution of the junior structural design course that is the focus of this paper is summarized in Table 1. Specific details regarding course structure such as enrollment, number of sections, and class meeting times are given to provide context for the discussions on specific components of the inverted classroom format that follow.

Table 1 – Evolution of Structural Design Course Format(s) at Villanova University

Semester	≤ Spring 2011	Spring 2012	Spring 2013	Spring 2014	Fall 2014
Course Number	CEE 3412	CEE 3412	CEE 3412	CEE 3402	CEE 4404
Course Title	Structural Design	Structural Design	Structural Design	Structural Steel Design	Reinforced Concrete Design
Credit Hours	3	3	3	3	3
Instructor	Professor A	Professor A	Professor A	Professor A	Professor B
Lab Integrated Into Course?	No [a]	No [a]	No [a]	Yes	Yes
Required/Elective	Required	Required	Required	Required [b]	Elective [b]
Typical Student Rank	2nd Semester JR	2nd Semester JR	2nd Semester JR	2nd Semester JR	1st Semester SR
Class Meetings (per week) [c]	3 x 50 minutes	3 x 50 minutes	3 x 50 minutes	2 x 75 minutes	2 x 75 minutes
Format	Classic	Inverted	Inverted	Inverted	Inverted
Student Had an Inverted Course in CEE Prior to This?	No	No	No	No	Yes
Total Enrollment [d]	59 [e]	47	46	47	31
# of Sections	2	2	2	2	1

[a] CEE 3912 – Structural Engineering Laboratory offered as a separate required co-requisite 1-credit required course that meets for one 180-minute period every other week
[b] Students must take either CEE 3402 or CEE 4404 to graduate, but typically would only take CEE 4404 without also taking CEE 3402 if they are off sequence
[c] Academic semester is 14 weeks long
[d] Total enrollment of all sections
[e] Three-year average (2009 to 2011)

Motivation

Courses such as this undergraduate Structural Design course focus primarily on the lowest three tiers within the classical presentation of Bloom's taxonomy, as shown in Figure 1. Students must develop a knowledge and comprehension of basic structural behavior and implement it in an applied form. Higher levels of learning are more formally addressed in courses such as Capstone Design, where students take much of the same content from a course such as Structural Design, implement it in a unique context, and consider different alternative solutions with recognition of broad economic, societal, and other impacts. In Structural Design, students are often presented with straightforward systematic problems on an exam such as "Design a reinforced concrete beam to span a length of X to resist a load of Y, using Z strength concrete." These types of problems have either a single correct answer or a very limited number of acceptable reasonable answers. Though the course has "Design" in its title, the content in many respects is better communicated as the "building blocks of design". While students are indeed required to think creatively at certain points within the course, creative design is not the true essence of the course the way that it is in a capstone design course.

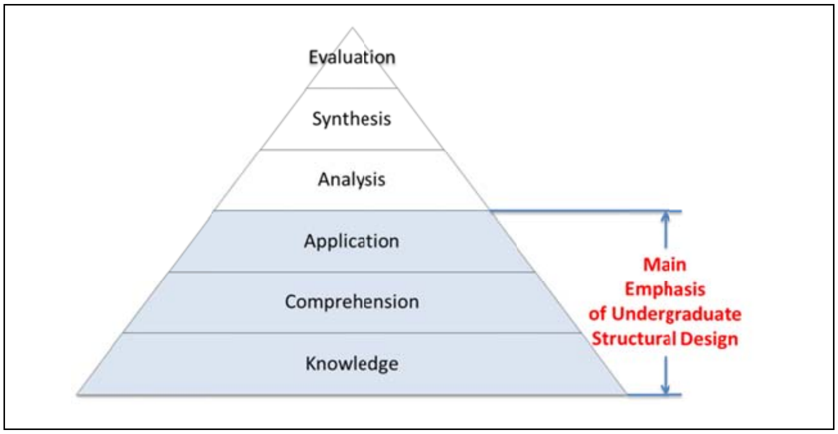


Figure 1 – Bloom's Taxonomy as it relates to Structural Design course

Most instructors in structural design courses, including the authors of this paper, feel that the "theory" related to the lowest two levels of Bloom's taxonomy is extremely important in this type of course. Despite this, assessment of student performance via exams and other course elements is overwhelmingly based on the application level, with design questions such as that introduced in the previous paragraph. Instructors want students to be able to design a steel beam for a building structure using a systematic approach that ensures life safety and serviceability, but also to understand exactly what they are doing, what behavior design equations reflect, and how changing certain parameters will affect the design solution. At this level, structural design is all about systematic application of principles and equations, but the application must be done in an educated manner.

The decision to shift from a more classical course structure to an inverted classroom format in the Structural Design course discussed in this paper was motivated by a number of factors. Foremost was the recognition that it makes little sense to focus most of the precious class time, where faculty and students are able to interact, on knowledge and comprehension, while using primarily application problems for evaluation of student performance. The inverted course format, particularly with a requirement for students to watch theory-based lectures prior to coming to class where they work on application problems, addresses all three lower levels of Bloom's taxonomy in a comprehensive, logical manner. Students prepare for the application level by initially addressing the lower two levels on their own, and then the instructor can structure problem-based learning in the classroom to focus on all three levels by embedding and reinforcing theoretical points within the development of the problem solutions.

The faculty member in charge of the original CEE 3412: Structural Design course (Professor A, one of the co-authors of this paper) also felt that with each passing year students were becoming less and less engaged in the classroom during lectures. The course had always received very good reviews and students indicated that they felt they had learned a lot on end-of-course surveys and via more informal means of feedback, but activities inside the classroom were structured in a very passive learning format. Most class meetings consisted of a PowerPoint based lecture, perhaps including an example problem that was pre-solved and included in the lecture slides. Students were assigned homework problems and if they ran into difficulty they would have to seek out help from the instructor outside of class or from their peers. In the end, the instructor felt that students were learning the material because the course was well organized and the lecture notes were thorough, but that with more engagement inside the classroom students could learn more efficiently and more effectively for the long term.

At the time the instructor considered changing the course to the inverted format, there were no true inverted courses offered in the College of Engineering at Villanova University, but the trend toward inversion was beginning to gain momentum nationally, especially at the pre-college level. Several graduate-level courses had been offered in a synchronous or asynchronous distance education mode within the college, including by the authors, and the instructor was quite comfortable with the logistics related to recording lectures. Technology had evolved to a point where developing, recording, editing, and publishing lectures for remote viewing was a relatively simple (though time-consuming) exercise. Just as important is the fact that undergraduate students in this generation have been immersed in mobile technology for most of their lives and are not alienated by the concept of watching lectures online.

Based on these considerations and observations, Professor A decided to switch the course to an inverted format with the Spring 2012 offering of CEE 3412. This decision was supported by the instructor's colleagues, department chair, and college administration, which provided some support and resources for implementing this new approach. On the heels of the initial offering of this course in 2012, the college developed a more comprehensive pilot program including multiple inverted courses in each department. Though there are perceived potential faculty time savings in the long-term with this approach, the primary motivation for the development and implementation of the inverted classroom in the Structural Design course (now two courses) and other courses within the college remains a focus on improvement and efficiency in student learning. In simple terms, the inverted classroom is thought to make the best use of in-class time and provide a better structured learning environment within the context of how all of the time in a course (both inside and outside of class meetings) is utilized.

Many lessons have been learned as the course in structural design has evolved from the initial inverted class offering in Spring 2012 to the two separate inverted course offerings in steel design and concrete design in Spring and Fall 2014, respectively. The remainder of this paper focuses on how the numerous distinct elements that constitute an inverted format for these courses work, both individually and as part of the course as a whole. These elements include recorded lecture videos, quizzes related to videos, problem sets (example problems and homework), laboratory periods, design projects, and course binders.

Overall Changes in Course Structure

The introduction of the inverted class format has led to significant changes in the way that time is spent during class meetings. As seen in Figure 2, prior to inversion about half of the total class meeting time was spent on lecture content. Only about a quarter of the total class time was spent on problems, and all of these problems were presented as example problems with the instructor completely leading the solution. In many cases, complete or partial solutions were given in the notes to facilitate a fast-track completion of the problem before the class meeting period ended.

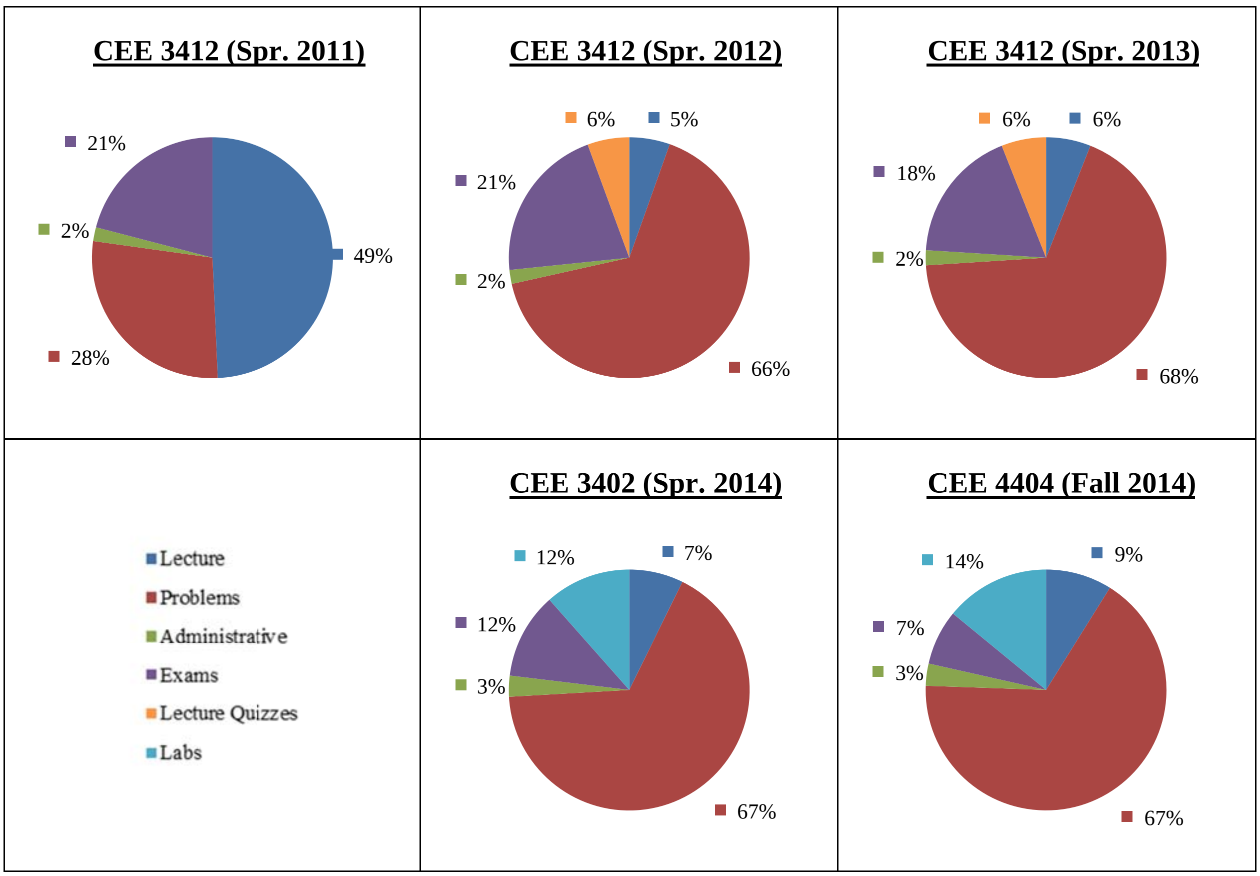


Figure 2 – Percentage of class meeting time spent on different types of activities

After inversion, the amount of time spent on lecture content during class meetings was drastically reduced to less than 10 percent. As a result, approximately two-thirds of the in-class time was able to be spent on problem solving. Not only are more problems solved than in the pre-inversion course, but the problems are solved in real-time and with more discussion of the concepts demonstrated by the problems. Further details on the structure of each of the components presented in the graphs of Figure 2 are presented in later sections of this paper.

Assessment

A true assessment of the impacts that implementing the inverted format have had on student learning is difficult to achieve given the complete restructuring of the courses including the manner in which exams have been implemented and overall grades computed in each successive course offering. Furthermore, as the decision to switch formats was done in between successive course offerings there was no opportunity to go back in time to construct specific assessment tools for comparison between the classic and inverted formats. Still, a broad comparison of student performance can be made by examining course grades.

Figure 3 presents a plot showing average examination scores for the structural design courses at Villanova University from 2009 to 2014. Average examination scores can best be defined as final course grades (out of 100 percent) if all non-exam elements of the final grade such as homework, laboratories, projects, lecture-based quizzes, attendance, or anything else are removed. Grades are still weighted within each course such that if Exam B was worth more than Exam A it is weighted more heavily in the computed score used for the plot.

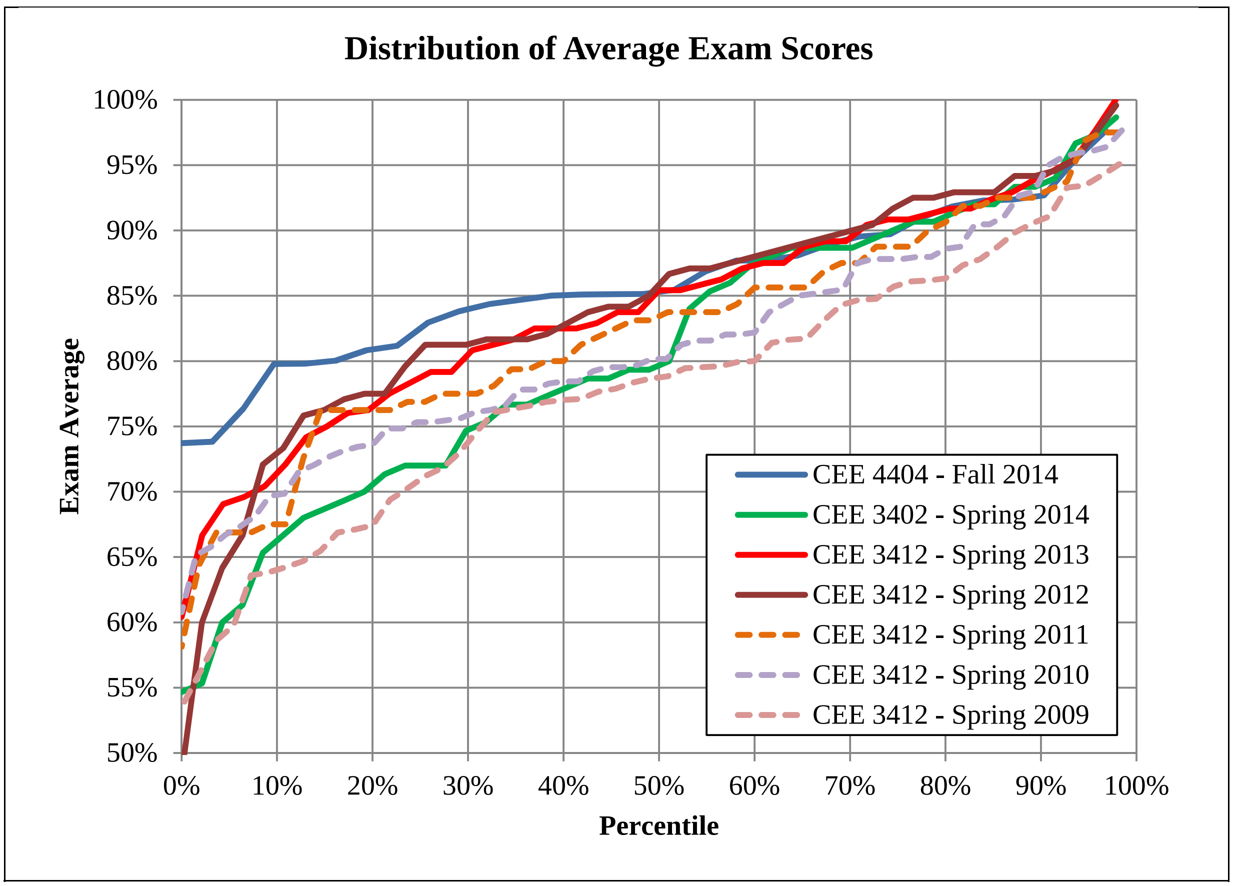


Figure 3 – Distribution of exam scores in all structural design courses at Villanova University from 2009 to 2014

Several trends are apparent in Figure 3. First, the inverted courses generally indicate better overall student performance on exams than the non-inverted courses, especially within the middle two quartiles of students (between the 25th and 75th percentiles). Inverted courses are represented on the plot by solid lines, while non-inverted courses are represented by dashed lines. This implies that over this middle range of students, students are more prepared for application-based examination problems than they were in the classical (non-inverted) format.

Another trend can be seen specifically with the new separate courses in steel (CEE 3402) and concrete (CEE 4404) design as compared to the previous combined offering of CEE 3412. For the inverted courses offered from 2012 on, there is little difference in student performance within the top half of the students. Large differences can be seen in the lower half of students within a particular course, however. Students in the lower half of CEE 4404 performed much better than those in the lower half of the other inverted courses. It is hypothesized that this is because the students in this elective course are self-selecting and likely have a moderate to strong interest in structural engineering. Enrollment data for each course was shown in Table 1, and it can be seen that 31 students took CEE 4404 in Fall 2014. All but one of these 31 students took CEE 3402 in the previous semester, while the 17 of the 47 students in CEE 3402 did not enroll in CEE 4404 and instead chose other electives outside of structural engineering. It is also possible that the fact that CEE 4404 was taught by Professor B whereas the other courses were taught by Professor A plays a minor role in the grade differences for this course.

Additionally, it is worth noting that the Spring 2014 semester was severely impacted by winter weather closures. Approximately one-quarter of the course meetings in CEE 3402 that semester were cancelled or delayed, including nearly half of the periods during the first half of the semester. This required makeup meetings to be held on weekends during the second half of the semester per university policy. The end of the semester became very compressed and students did extremely poorly on two of the three questions on the final exam. The mean scores on these two questions were 65% and 73%, respectively. If these two questions – which constitute about a quarter of the total exam grade for the course – are removed from the comparison, then the student performance for this course actually exceeds the student performance for all of the other inverted courses for the top half of students, and falls in line with the student performance in the inverted CEE 3412 courses for the lower half of students.

Valuable assessment data has also been gathered with each offering of the course in an inverted format using a comprehensive student survey administered at the end of the semester. Data from this survey will be shown throughout the remainder of this paper as a means of presenting student perceptions on the strengths, weaknesses, and impacts of the inverted class format. These surveys were administered by handing out the survey during the last week of class and requiring students to submit it before the final exam, which ensures a near 100% return rate. The surveys were anonymous and included approximately fifty multiple choice rating questions and an opportunity for open student comments at the end of the survey on anything related to the inverted format of the course. Surveys used a simple 1 to 5 scale for responses:

1 = Strongly disagree
2 = Mildly disagree
3 = Neutral
4 = Mildly agree
5 = Strongly agree

Table 2 – Student responses on survey questions related to the use of the inverted class format

	Spring 2012	Spring 2013	Spring 2014	Fall 2014
	CEE 3412	CEE 3412	CEE 3402	CEE 4404
	Structural Design	Structural Design	Structural Steel Design	Reinforced Concrete Design
	Professor A	Professor A	Professor A	Professor B
I have met the individual course objectives for this course. [a]	4.3 (4.1 – 4.6)	4.6 (4.4 – 4.8)	4.7 (4.6 – 4.9)	4.6 (4.3 – 4.8)
I feel that the format of this course improved my overall learning over a classical in-class lecture format.	3.7	4.3	4.4	4.6
I feel that the format of this course improved my conceptual understanding of structural behavior over a classical in-class lecture format.	3.5	3.7	3.8	4.1
I feel that the format of this course improved my ability to apply knowledge in solving basic structural design problems over a classical in-class lecture format.	4.0	4.3	4.2	4.5
I would prefer all of my similar (standard CEE, math, science lecture/problem solving-type) courses use the format that this course did.	2.5	3.3	3.5	4.2
In hindsight and specifically for this course, I prefer the format of this course over a traditional in-class lecture format.	3.3	4.2	4.4	4.6
I feel that the format of this course required a more substantial investment of my time over a classical in-class lecture format.	4.5	4.1	2.4	3.3

[a] Since specific course objectives vary by course, this response is presented as an average response for all objectives in that course. Actual survey data is broken down by individual course objective. The range of mean responses for individual outcomes is shown in parentheses.

Table 2 summarizes student responses on general questions related to the use of the inverted class format. The responses clearly indicate an increasing acceptance of the inverted format by the students in each successive offering. These findings are consistent with the instructors' feelings that the course improved significantly as the inverted format was refined between the first and second offerings, and then even more as the original course was split into separate steel and concrete courses with integrated labs. It is also important to note that with the separate steel and concrete offerings in Spring 2014 and Fall 2014, respectively, the inverted format has been well accepted by students in courses offered by two different instructors.

Overall, students feel that the inverted format improves their overall learning and ability to apply knowledge, which makes sense given the problem-centric nature of the inverted courses. To a lesser extent, but just as important, students feel that the inverted format improves their conceptual understanding. Students indicate a clear preference for this format in these structural design courses, and their interest in having the inverted format implemented in other technical courses is growing with each successive offering.

A clear trend that is also important to note is that students in the 2014 offerings of steel and concrete did not feel that the inverted format required a more substantial investment of time on their part. Students in the 2012 and 2013 offerings before the split did, however, perceive a substantially larger time commitment. There is no question that the content was overwhelming in the original CEE 3402 course since steel and concrete were both being covered in the same course. The course simply had too much material and that was the primary motivation for the departmental decision to restructure the course sequence. Furthermore, differences in the length and number of recorded videos, and in how quizzes on video content were implemented within the course probably contributed to this perception. These issues will be discussed in more depth later in this paper. Regardless of the reasoning however, it is logical to conclude that there is a correlation between the students' perceived time commitment and their acceptance of the inverted class format.

Lecture Videos

Recorded lecture videos are a critical component of the inverted course structure since students are required to watch these theory-based lectures online before coming to class to work on problems that apply this theory. These videos are posted on a course learning platform such as BlackBoard or Mediasite for student viewing. While students are required to view the lectures before class, they are also able to go back and review the lectures as needed for further understanding once they have been introduced to how to apply the theory.

For the first inverted course in Spring 2012, lectures were recorded using the College of Engineering's distance education facilities, which results in lectures that include both video of the instructor presenting the lecture and the presentation. The same recorded lectures were used for the second offering of the course in Spring 2013. When the decision was made to split the course into separate steel and concrete courses, it became appropriate to re-record the videos for several reasons. First, this allowed the videos to be consistent with the new course structure including course names, numbers, and more importantly calendars and syllabi. Secondly, feedback from the first two offerings indicated that it was desirable to break lectures into smaller segments rather than the large single segments that were initially used. Finally, this allowed for consistency between in-class and out-of-class style and terminology since the faculty member (Professor B) teaching the new concrete course was not previously involved with the content in the original course.

While many specific lecture slides could be reused because the content had not changed, all lectures were re-recorded before the first offering of either CEE 3402 or CEE 4404. New recordings were made using Camtasia screen-capture recording software such that there was no need for the use of college staff or facilities. Furthermore, the use of Camtasia greatly expanded the ability to edit lectures after the initial recording was made. The videos produced using Camtasia included only voice and screen capture, and the instructor does not appear in the videos. No negative comments have been received from students regarding the lack of video to complement the audio recording of the instructor.

Statistics related to the recorded lectures used in each inverted course are shown in Table 3. Note the dramatic difference in lecture lengths between the initial inverted offerings of the combined steel and concrete course as compared to the more recent 2014 offerings of the separate courses. Despite the course content remaining essentially the same, the total lecture time has been cut in half and distributed over two courses. This was the result of a concerted effort on the part of both instructors to keep the new recorded lectures short and very focused. Points are not repeated multiple times in the lectures because the important lecture content will be emphasized within the problems solved in class. Extra comments and stories that deviate significantly from the core content are not included, or are edited out before publishing the lecture video. The recognized goal is to prepare students by providing them the necessary background theory and a few key takeaways before getting into the problem solving sessions in the class meetings. As noted previously based on the results of student surveys, the shortening of lectures has had a tremendous benefit on the perceived time burden associated with the inverted class structure. There is no question that this improvement has had a great positive impact on the success of the inverted format in the new courses.

Table 3 – Statistics on recorded lecture videos for each inverted class offering

		Spring 2012	Spring 2013	Spring 2014	Fall 2014
		CEE 3412	CEE 3412	CEE 3402	CEE 4404
		Structural Design	Structural Design	Structural Steel Design	Reinforced Concrete Design
		Professor A	Professor A	Professor A	Professor B
Number of recorded lectures [a]		31		38	22
Recorded lecture length	Mean	39:40		9:18	12:36
	Median	38:49		8:57	12:21
	Minimum	18:05		4:04	8:05
	Maximum	69:59		13:40	19:42
	Total	20:29:23		5:53:25	4:37:20
Percentage of course grade allocated for watching lecture videos		none	none	2.2%	none

[a] Considers only lectures recorded for viewing outside of regular class meetings

Table 4 – Student responses on survey questions related to recorded lecture videos

	Spring 2012	Spring 2013	Spring 2014	Fall 2014
	CEE 3412	CEE 3412	CEE 3402	CEE 4404
	Structural Design	Structural Design	Structural Steel Design	Reinforced Concrete Design
	Professor A	Professor A	Professor A	Professor B
I watched the lecture videos.	4.1	3.5	4.7	4.4
I learned a lot from the lecture videos.	3.3	3.1	3.9	3.6
The lecture content provides a strong background for solving the problems in the problem sets.	3.3	3.5	4.0	3.7
The length of the video lectures was appropriate.	N/A	N/A	4.5	4.4

Additional responses from student surveys related specifically to questions on recorded lecture videos are shown in Table 4. Students indicate that they are generally watching the videos as required on the syllabus, and that they are learning from the videos. Clearly however, the students feel that they do not learn as much from the lectures as they do from solving problems inside and outside of class. This is not surprising and is consistent with the initial observation by Professor A that students were less engaged during lecture content than during problem-based content.

Quizzes

Lecture-based quizzes are a critical component that complements the recorded lecture videos. Quizzes have been constructed using one to five multiple choice based questions that emphasize theoretical concepts and do not require extensive calculations. However, the manner in which lecture quizzes have been implemented, and the defined purposes for which they are used, have evolved over the different inverted class offerings since 2012. Important statistics related to these lecture-based quizzes are provided in Table 5. Student survey responses related to these quizzes are shown in Table 6.

In the original inverted course in Spring 2012 and then in the following Spring 2013 offering, quizzes were given at the beginning of the class meeting that followed the lecture viewing period. Quizzes could only be taken once, they were given on paper, and the instructor had to grade them manually. As demonstrated by both the grade performance shown in Table 5 and the student responses shown in Table 6, students did not like this format. Students felt that the quizzes were too “tricky” because it was too difficult to remember the critical information from a long lecture viewed the day or night before the quiz. The instructor would often observe students stressfully and hurriedly studying before the beginning of the class period, and students who watched the videos were frustrated by low quiz grades, particularly since the quizzes counted as 16% of the final course grade.

Table 5 – Statistics on lecture-based quizzes for each inverted class offering

	Spring 2012	Spring 2013	Spring 2014	Fall 2014
	CEE 3412	CEE 3412	CEE 3402	CEE 4404
	Structural Design	Structural Design	Structural Steel Design	Reinforced Concrete Design
	Professor A	Professor A	Professor A	Professor B
Number of lecture-based quizzes	30	30	50	22
Total number of quiz questions	100	100	100	43
Quiz implementation	at beginning of class	at beginning of class	online, before class	online, before class
# of times quiz may be taken	once	once	unlimited	unlimited
Grading mechanism	manual	manual	automatic	automatic
Percentage of course grade allocated to lecture-based quizzes	16 %	0 to 10% [a]	4.4%	5%
Average composite quiz grade	71.2%	63.9%	96.9%	96.5%

[a] Composite quiz grade could be used to replace an exam grade. Each exam worth 10%.

Table 6 – Student responses on survey questions related to lecture-based quizzes

	Spring 2012	Spring 2013	Spring 2014	Fall 2014
	CEE 3412	CEE 3412	CEE 3402	CEE 4404
	Structural Design	Structural Design	Structural Steel Design	Reinforced Concrete Design
	Professor A	Professor A	Professor A	Professor B
Quizzes encouraged me to watch the lecture and learn the material in the lecture.	3.9	3.5	4.2	4.4
The questions asked on concept quizzes were focused on appropriate material and concepts.	3.3	4.2	4.9	4.5
The quizzes count as an appropriate part of my overall course grade.	2.3	3.4	4.2	4.2

In order to improve the vibe within the course, the quizzes were recast in 2013 as something that could only be helpful to the students' final course grades. Students were able to use their composite quiz grade to replace their lowest exam grade, so the quizzes would count anywhere from zero to ten percent of the grade. Unfortunately, this did not have the desired effect on changing students' attitudes towards the quizzes. Many students simply abandoned the idea of watching the lectures and studying for the quizzes, and simply guessed. This was especially apparent later in the semester. Many of these students were those who were doing well on the exams and simply didn't need the quizzes to help their course grade. The composite quiz average dropped all the way to 63.9 percent, as shown in Table 5. Note that at the same time, students were less interested in watching and learning from the recorded videos, as indicated by the responses in Table 4.

In the newer separate steel and concrete course offerings, the quizzes have been implemented in a completely different manner. Quizzes have been moved online and may be taken by the student immediately after they watch the lecture. Furthermore, the student is able to see his or her grade immediately and may retake the quiz as many times as desired until all questions have been answered correctly. The instructors also emphasize the role of the quizzes as a formative assessment tool, and encourage the student to learn from the quizzes, as the questions asked relate to the most important concepts from the lecture. This approach has made the quizzes a far more valuable course tool and as can be seen in the responses shown in Table 6, students are far more receptive to this quizzing approach. The weight of the quiz grade has also been reduced to about 5 percent of the course grade, which has reduced the stress level that some students have with regard to the quizzes.

In CEE 3402 (Spring 2014), the instructor also allocated just over 2 percent of the course grade as credit for watching the lecture videos. Although the authors don't feel that this is absolutely necessary, this was done as a means to discourage a student from simply logging on and guessing at quiz responses without watching the lectures. Based on the student responses shown in Table 4, students report that they are indeed watching the lecture videos. The instructor did not actually check on the students for this small portion of the course grade because it was not perceived to be worth the time investment required to track this data. However, as technology improves it is becoming much easier to obtain data on whether students actually watch the videos, when they watch the videos, and whether they watch the entire video. If this data can be gathered easily, then it may be evaluated in future course offerings rather than considering these as free motivational points toward the final course grade.

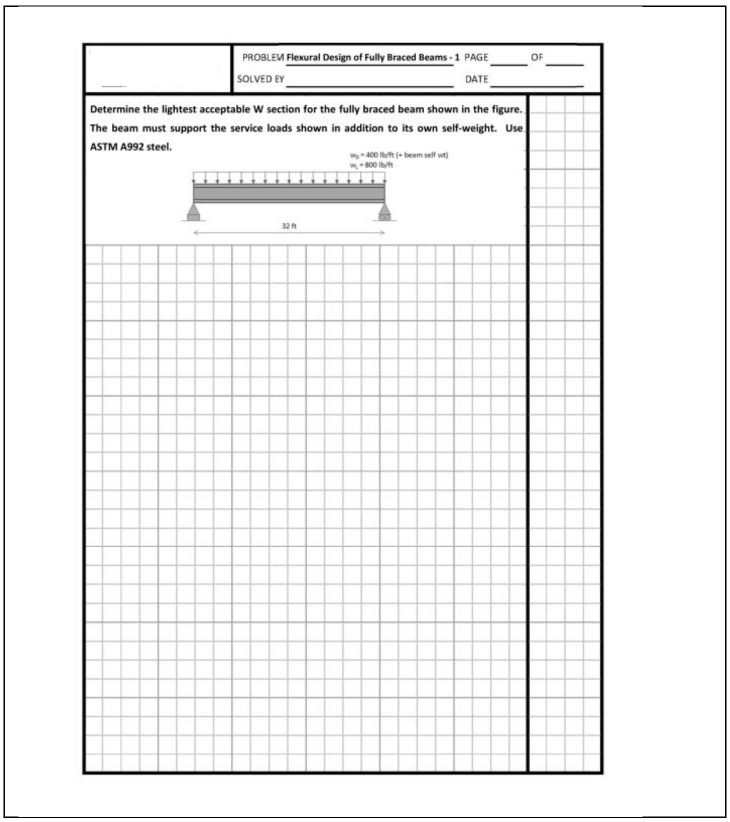
Problem Sets (Example Problems and Homework)

Problem sets constitute the primary application-oriented element in the inverted course structure. Problem sets include problems solved inside of class, those solved partially inside of class, and those solved entirely for homework. To reflect typical practice in structural engineering, all problems are solved on computation paper (on paper by the students and using digital ink on a TabletPC by the instructor) and to save time, the problem statement is provided at the top of the page that is distributed to students. An example problem set page is shown in Figure 4.

In organizing each course, the instructor has a plan for which problems will be primarily examples and which will be primarily homework. The problems intended to be used as examples are approached in a variety of ways, depending on the problem and complexity of the topic. In some cases, the problem may be solved entirely by the faculty member, with students following along. With such problems, the instructor uses the problem as an opportunity to reinforce the theory from the lectures and emphasize how that theory relates to the application in the problem. This approach, with what might be called "hidden" lecture content, is essential for extending the student's ability to problem solve past the basic level of just following a systematic design procedure.

Other problems may be solved partially or entirely in the class by students working individually, or occasionally in a small group. In these cases, the instructor may help to structure the solution into discrete steps and ask the students to check their solution at intermediate parts along the way. In other cases, the students may work on the entire problem on their own and then the instructor may ask for student assistance in solving the problem for the whole class as a means of verifying answers and emphasizing key points. In yet other cases, the instructor may ask students to work through a certain portion of the problem on their own in class, check their intermediate answers, and then ask them to complete the rest for homework.

The ability to work through problems using various techniques is an illustration of how the flexibility of the inverted classroom can be leveraged in different ways. Undoubtedly, certain methodologies apply better to certain types of problems and appeal to certain types of students but the ability to use a varied approach is critical. It was difficult to use as widely varying an approach in the original inverted class (CEE 3412) as compared to the newer courses (CEE 3402 and CEE 4404) because there was so much content to get through with both steel and concrete in one course. Furthermore, the authors feel that scheduling the new courses with two 75-minute periods that meet twice each week instead of the three 50-minute periods is critical because it allows for much better implementation of this flexibility in the longer period.


PROBLEM Flexural Design of Fully Braced Beams - 1 PAGE ______ OF ______
SOLVED BY ______________________ DATE ______________

Determine the lightest acceptable W section for the fully braced beam shown in the figure. The beam must support the service loads shown in addition to its own self-weight. Use ASTM A992 steel.

Figure 4 – Example problem set page

Table 7 – Student responses on survey questions related to problem sets

	Spring 2012	Spring 2013	Spring 2014	Fall 2014
	CEE 3412	CEE 3412	CEE 3402	CEE 4404
	Structural Design	Structural Design	Structural Steel Design	Reinforced Concrete Design
	Professor A	Professor A	Professor A	Professor B
I feel that the problem sets are the most important part of this course.	4.6	4.9	4.9	4.8
Solving problems in class helped me prepare for solving problems on my own.	4.6	4.8	4.8	4.9
The balance between problems solved in class and outside of class was appropriate.	4.0	4.7	4.1	4.5

Student survey responses related to problem sets are shown in Table 7. It should come as no surprise that in such application-focused courses, the students feel that these problems are the most important part of the course. Students strongly feel that solving problems in class helps them prepare to solve problems on their own, and students generally feel that the balance between problems solved in class and out of class is appropriate.

Laboratories

As noted previously, there were no integrated laboratories in the original CEE 3412: Structural Design course. Instead, there was a parallel laboratory course that was taught by a different faculty member than the design course. Over the years, the laboratory and design courses became less synchronized due to logistical challenges such as scheduling, and having different faculty members teaching these courses sometimes led to confusion and repetition of content. As can be seen in the responses within Table 8, students were fairly neutral on whether the lab and design courses complemented each other.

With the curricular restructuring that split steel and concrete into two courses, faculty in the structural engineering group felt that student learning would be greatly improved by integrating the laboratories into the design course. This presented a logistical challenge since the class meetings are only 75 minutes in length, but the instructors were able to work closely with the laboratory manager to design three very streamlined exercises for each course. Students spend three or four class periods in each course working in the laboratory on testing a structural element or series of structural elements. For CEE 4404, one period is spent building beams to show firsthand how constructability is greatly affected by design. These beams are then tested during a later class, requiring two class meetings for one lab.

These laboratory exercises were refined prior to the first course offerings through a series of practice runs to ensure that the laboratory could be conducted within the 75 minute time frame while still collecting all necessary data. Students are not required to write formal laboratory reports in these courses, but instead are required to make calculations related to the test specimen(s) either before or after the laboratory meetings. These calculation-based assignments also may include short writeup requirements where students are required to comment on something from the lab or the related data in one or two paragraphs. These assignments count for approximately 10 percent of the grade in CEE 3402 and less in CEE 4404 (where it is considered as part of the same segment of the course grade as problem sets). The lack of a formal lab report requirement is not viewed as a concern because the students get many opportunities to write formal laboratory reports in other courses throughout the CEE curriculum.

Student survey responses shown in Table 8 indicate that the students feel that the labs are constructive, and that the integrated laboratory structure works well compared to having the lab in a separate course.

Table 8 – Student responses on survey questions related to laboratories

	Spring 2012	Spring 2013	Spring 2014	Fall 2014
	CEE 3412	CEE 3412	CEE 3402	CEE 4404
	Structural Design	Structural Design	Structural Steel Design	Reinforced Concrete Design
	Professor A	Professor A	Professor A	Professor B
Overall, this course and the separate lab course (CEE 3912) complemented each other well.	3.5	2.5	N/A	N/A
This course would be better if the lab component were a separate entity (not merged within the course).	N/A	N/A	2.2	2.3
The labs in this course were constructive and helped my overall learning.	N/A	N/A	4.2	4.1

Design Projects

Semester long projects have been implemented into the inverted courses, with the exception of CEE 3412 in Spring 2013 when it was felt that there was not enough time for it (based on student feedback from 2012). These involve four to six unified design problems that relate to a single structure introduced at the beginning of the course. For example, a concrete building structure is introduced and then at different points throughout the semester students will design a slab, beam, girder, and column for that structure. These problems may require a little bit deeper thought and more work to develop the design loads through analysis than typical problem set problems. Some class time is dedicated to allowing students to solve these problems and receive faculty feedback.

These projects are solved individually rather than in groups, and students make submissions on the different parts throughout the semester. Depending on the course, the project may count for as much as 15 percent of the final course grade. Future plans include developing a single structure that can be used for the same project in both steel (CEE 3402) and concrete (CEE

4404), as well as in the course that students take before these courses (CEE 3401: Structural Analysis).

Course Binders

The student course binder is a critical organizational element that has been used in all of the inverted courses discussed in this paper. An example of a course binder can be seen in Figure 5. Students purchase the binder from the department at cost on the first day of class. The binder has the course syllabus and calendar, all of the lecture notes and problem sets, information on the design project and laboratory periods, and a large quantity of blank computation paper. Students are required to bring their binder to each class meeting. The use of a pre-prepared binder eliminates the need for posting lecture notes and other items during the semester, allows students to keep their printing budget for use in other courses, and most importantly ensures that students organize their course content in a manner that facilitates learning. The use of these binders has been extremely well received by students in these inverted courses.

Figure 5 – Example student course binder

Faculty Preparation

No quantitative measurements of faculty time were made during the preparation of any of the structural design course offerings. However, it was very clear to both instructors that the preparation time for an inverted course is significantly greater than for a standard course during the initial inverted offering. The additional time required depends if the course has already been prepared and delivered in a standard format, or if an entirely new course is being created. Both instructors found that inverting a course with existing course content takes approximately as much faculty time as creating an entirely new (non-inverted) course. Creating an inverted course using new course content increases the preparation time by roughly 50 to 75 percent when compared to preparing a new course in a standard format. As the authors' experiences demonstrate, it is also likely to require a few iterations through after the initial inverted course offering to achieve the desired steady-state format for the course.

The time required to invert a course is necessary to modify and record the lecture content, develop additional, more interactive problems to examine in class, and to structure and present the course in an organized fashion. As discussed previously, the inverted format is more effective when the lectures are delivered in shorter, more focused segments. It takes time to determine how to restructure and reorganize the lectures to fit this framework. Additional time must be spent recording, editing, and posting the lectures. Editing can be a quick process, or it can take a significant amount of time depending on the level of refinement desired and the quality of the initial recording. Quizzes must also be developed for each lecture.

Once the structure of the inverted course has been established, the preparation time for subsequent course offerings is expected to be similar to or slightly longer than for a standard course. While the preparation for each class meeting may be slightly reduced because most instructors find it easier to prepare for applied content such as solving problems than for delivering theory-based lectures, the larger amount of time required to manage the more complex logistics in an inverted course is often overlooked.

To work well, an inverted course structure requires an increased level of organization within the course. An inverted course structure has additional components that both the students and instructors must complete. In order for the course to be effective, the students need to be aware of what they are responsible for when, including watching lectures, taking quizzes, and completing problems sets or design project submissions. It is the faculty member's responsibility to present this information in a manner that is clear and concise and to ensure that the students have access to the materials needed to complete these assignments. Proficiency in using a course management system can be extremely useful in achieving this critical component of an inverted classroom.

Conclusions

This paper examines lessons learned through inverting an upper level undergraduate course in structural design. Based on the results of an extensive student survey, instructor experiences, and the assessment of student performance the following conclusions can be drawn:

- The inverted classroom format is well suited for application level courses and can improve student performance, specifically for the middle two quartiles of students (25-75% percentile)
- Students feel that the inverted classroom format improves their conceptual understanding of the material as well as their ability to apply that knowledge through problem solving over a more traditional classroom format
- Short, focused recorded lectures improve student acceptance of the inverted classroom format, resulting in an increased motivation to watch the videos and increased perception of the value of the videos to improve their theoretical understanding
- Quizzes can be an effective method for motivating the students to watch the videos and can also be used as a form of formative assessment when implemented in an appropriate manner
- The inverted classroom format provides the flexibility to solve problem in multiple ways to increase the student's problem solving ability

- The inverted classroom format results in a significant increase in the faculty preparation time during the initial offering, with similar preparation times to standard non-inverted courses once the inverted course has become established

Bibliography

1. Bishop, J.L. and Verleger, M.A., "The flipped classroom: a survey of the research," in Proc. ASEE Annual Conference, Atlanta, GA, USA, 2013, Paper ID# 6219.

2. M. Prince. Does active learning work? A review of the research. Journal of Engineering Education-a Washington, 93:223–232, 2004.

3. S. Zappe, R. Leicht, J. Messner, T. Litzinger, and H. W. Lee, ""Flipping"the classroom to explore active learning in a large undergraduate course," in Proc. ASEE Conf., Austin, TX, 2009, p. AC2009-92.

4. L. Bland, "Apply flip/inverted classroom model in electrical engineering to establish life-long learning," in Proc. ASEE Annual Conference Chicago, IL, USA, 2006, p. AC2006-856.

5. M. Lage, G. Platt, andM. Treglia, "Inverting the classroom: A gateway to creating an inclusive learning environment," J. Econ. Educ., vol. 31, no. 1, pp. 30–43, 2000.

6. J. Strayer, "The effects of the classroom flip on the learning environment: A comparison of learning activity in and traditional classroom and a flip classroom that used and intelligent tutoring system," Ph.D. dissertation, Dept. Educ., Ohio State Univ., Columbus, OH, USA, 2007.

7. Bidwell, Allie, "Flipped Classroom May Help Weaker STEM Students," US News and World Report, August 5, 2014.